Life-Cycles of Large Radiological Sources- Assessing RDD Concerns & Options

Gregory J. Van Tuyle

Evelyn Mullen

Los Alamos National Laboratory

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Introduction

- Large Radiological Sources could be used to Produce Large and Dangerous RDDs
  - Radiological Sources are in Wide-Spread Use Around the World
  - The Radioactivity Range Spans Many Orders of Magnitude
- Any Attempts to Deny Access to these Materials must be Focused
  - Too Many Sources in Use; Must Focus on Most Dangerous
  - Vulnerabilities Vary Throughout the Life-Cycles
- We Evaluated the Large Sources and Their Life-Cycles and Developed a Source Status Concern Index (SSCI) for Comparison
  - 8 Large Source Applications Evaluated at 8 Life-Cycle Stages
  - Significant Uncertainties and Some Details Masked, e.g., security
  - Rankings Appear Significant and Credible (Order of Magnitude)
- Options for Reducing Vulnerabilities were Evaluated for Potential Impact: Integrated Approach Can Reduce but Not Eliminate Concerns

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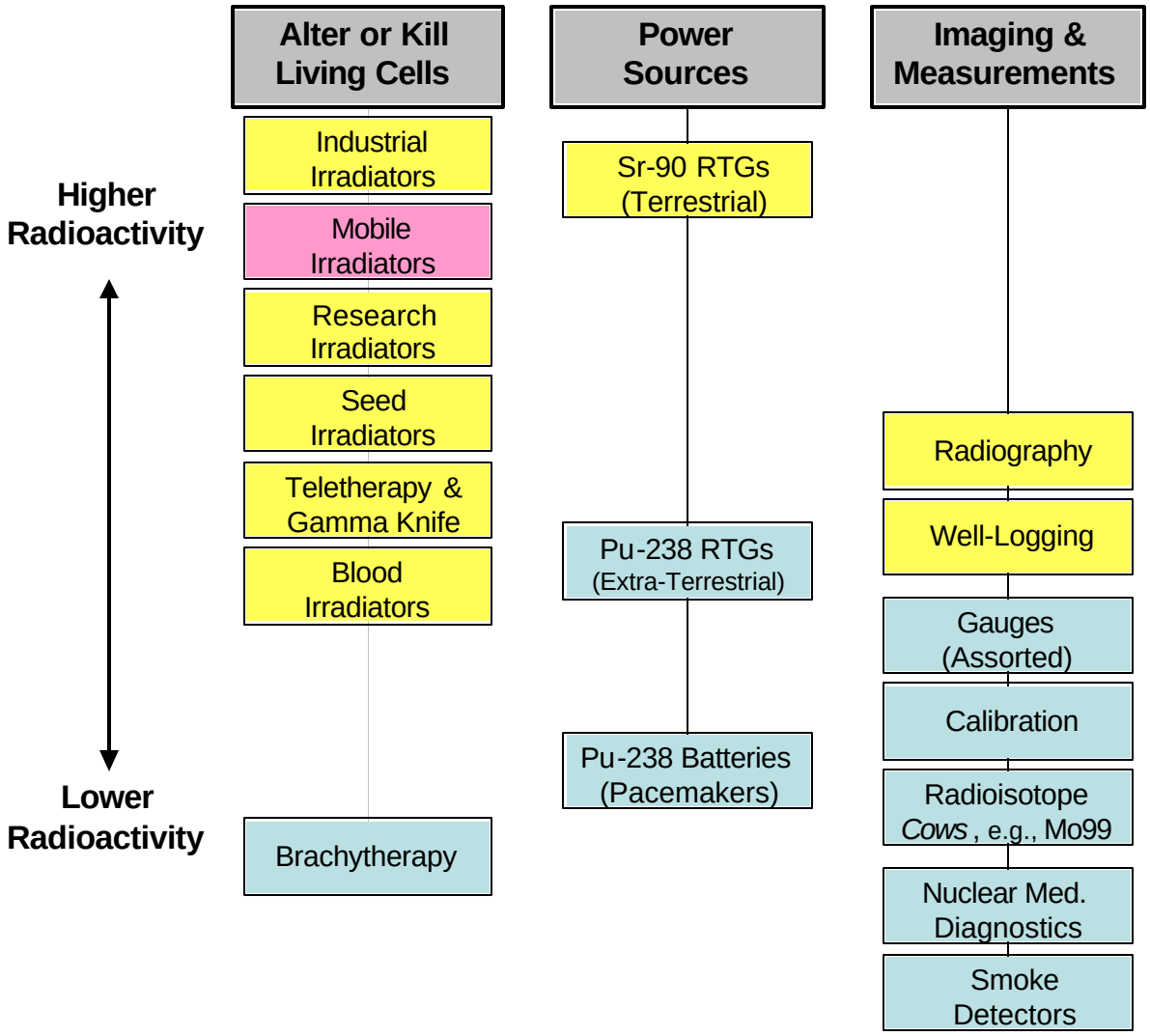
Hierarchy of Radiological Source Applications



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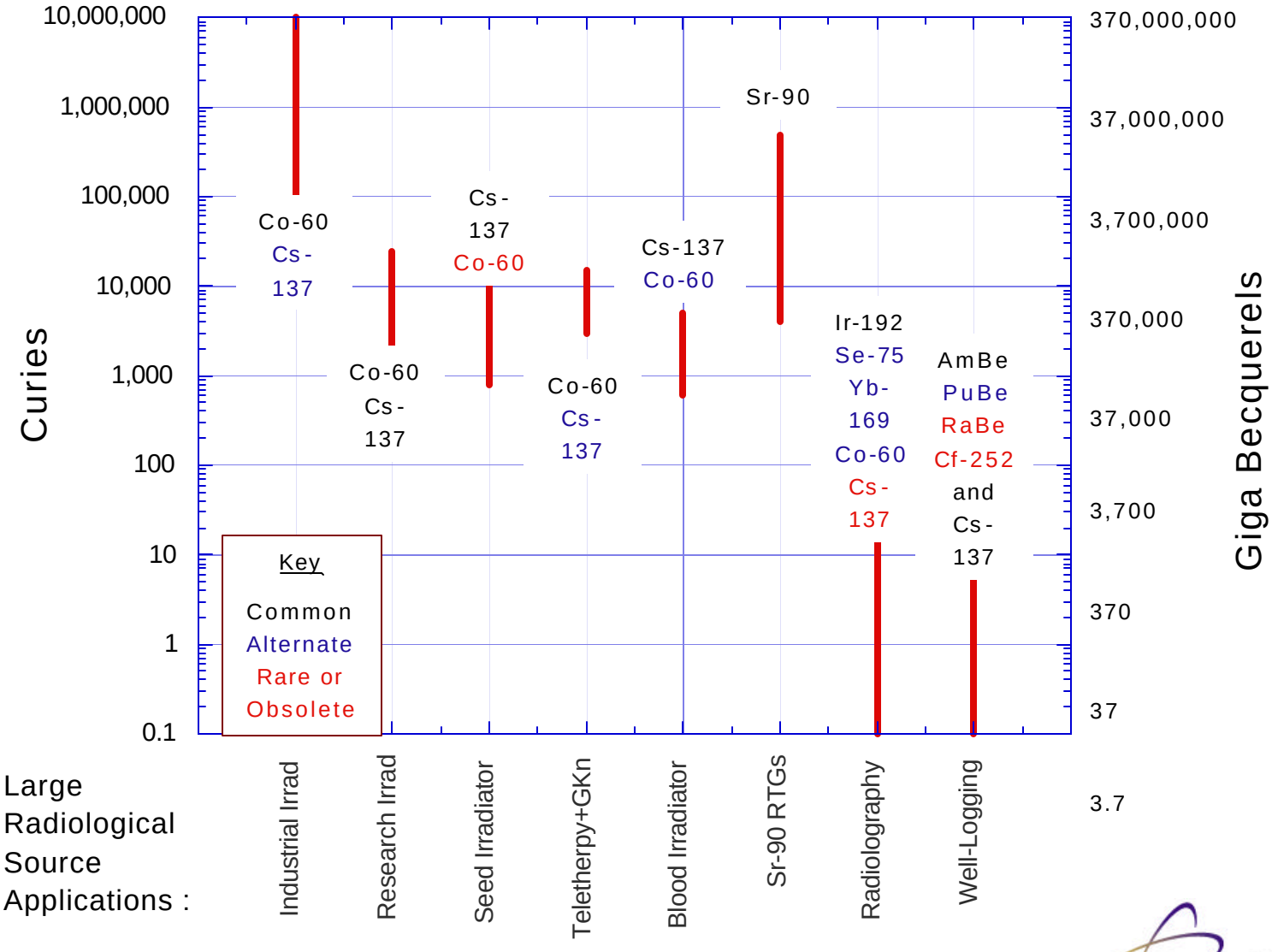
The Radioactivity Levels Span Many Orders of Magnitude



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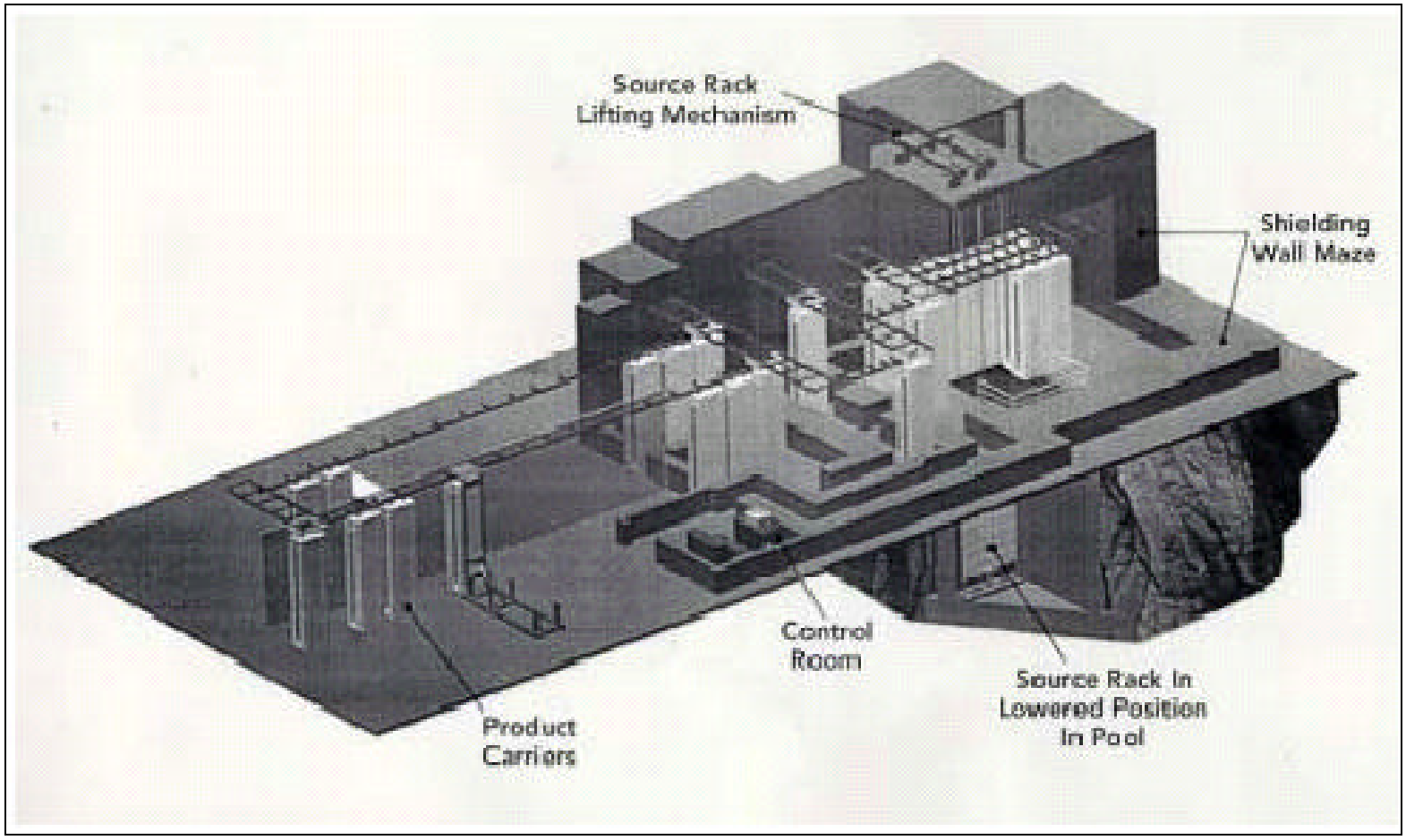
Large Industrial Irradiators Can Use Millions of Curies of Cobalt-60



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Teletherapy Units

Medical Teletherapy Unit Typical of Those Used in Central and Eastern Europe

Medical Teletherapy Unit, Vietnam

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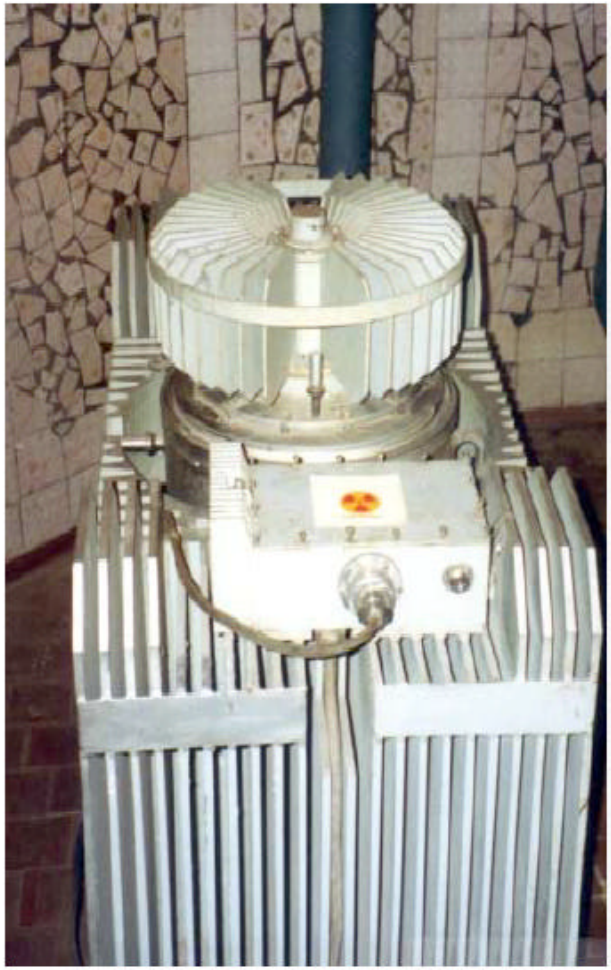
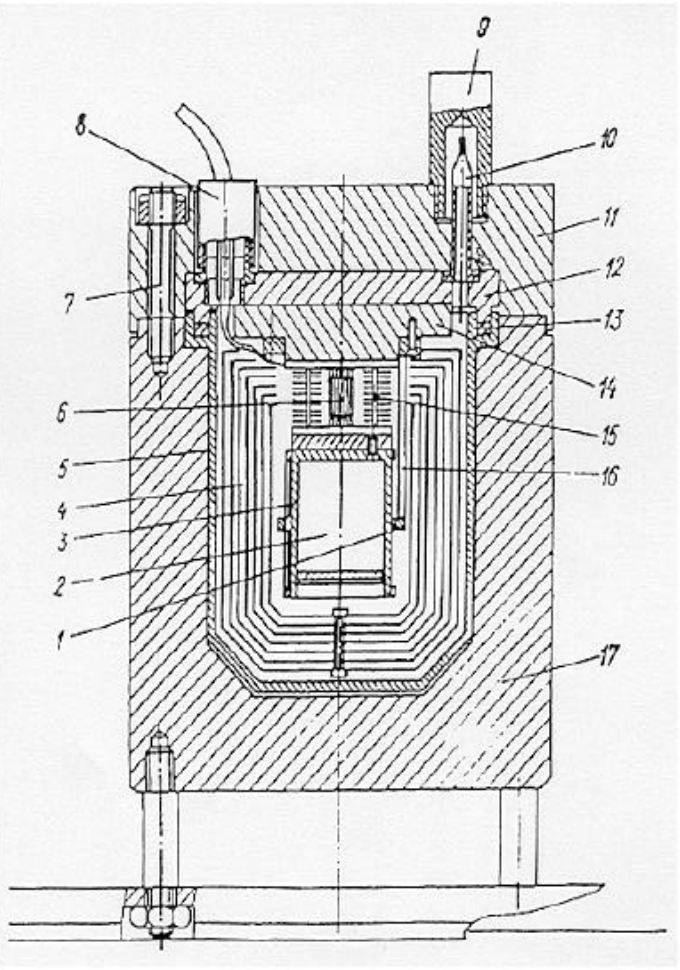
Sr-90 Radioisotope Thermal-Electric Generators





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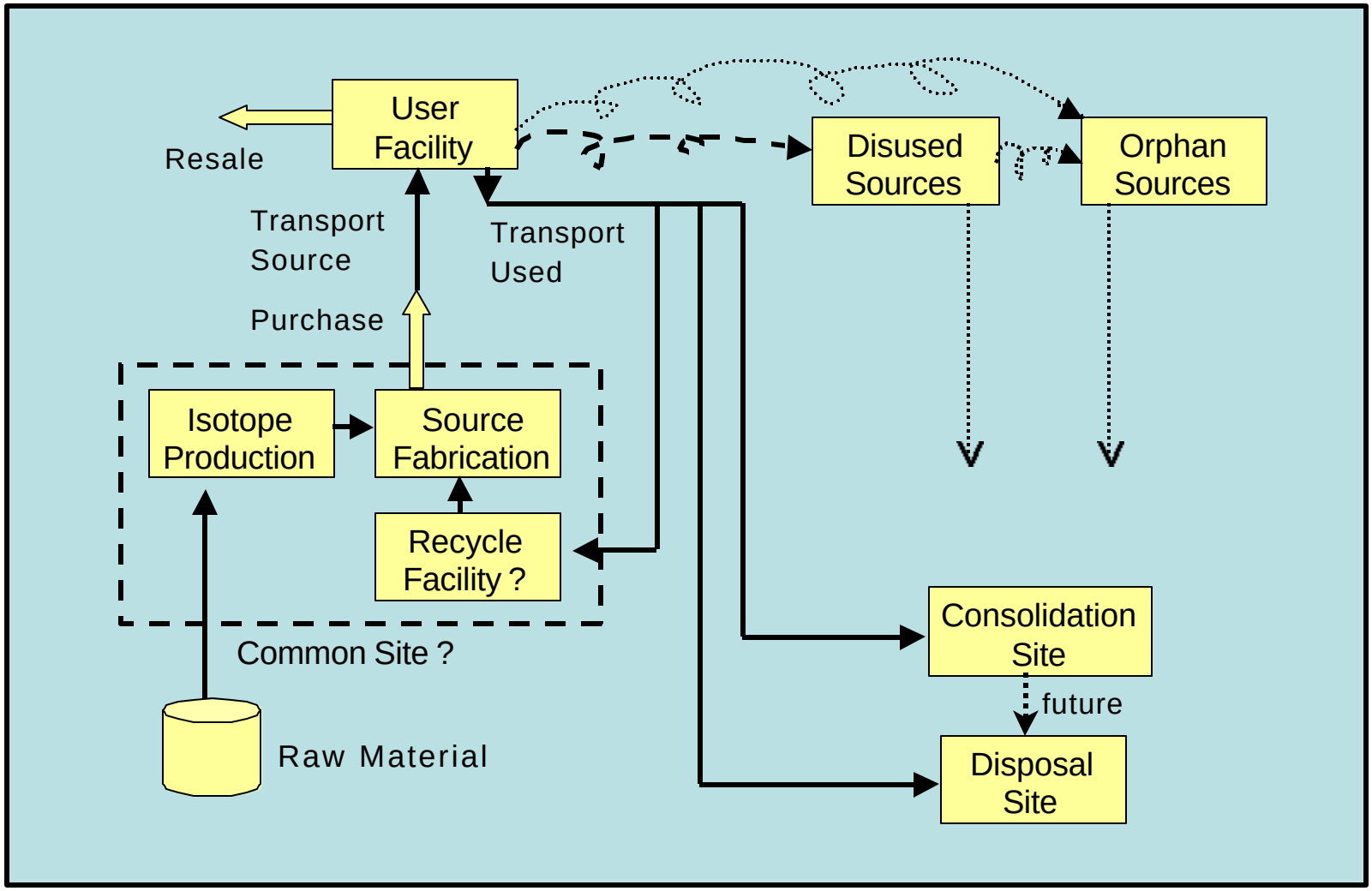
Radiological Source Life-Cycles are Impacted by Disposal Problems



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Source Status Concern Index (SSCI)

- To Support Cross-Comparisons Need a Parameter that Reflects Composite Hazards and Vulnerabilities
  - Number of Sources, Radioactivity Level, and Hazard (per Curie) Increase Concern; Inaccessibility and Security Reduce Concerns
  - Use Log(10) to Assist Interpretation (like Richter Scale for Seismic)

$SSCI = Log_{10}$(#Sources x Radioactivity x Hazard Factor / [Inaccessibility x Security])

- Estimated Numbers of Sources and Radioactivity Levels at Each Stage Based on Available Data & Insights
- Hazard Factor Based Only on Dose: 1 for β, 10 for γ, 100 for α
- Inaccessibility and Security Scores Estimated from 1 to 100
  - Examples: Source Suppliers Score 100 twice; Radiography Scores Low
  - Some Security Features Not Reflected in Scores and Results

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Table 2. Parameters Used for Base Case SSCI Analysis

Number of Sources		Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources		120	10	1	2500	150	20	12000	2000
Annual Sales		95	7	1	2000	100	10	12000	1000
Transported		190	7	1	4000	100	10	12000	1000
In Use		190	120	1	6000	1500	800	30000	10000
Disused		1	7	1	50	10	600	50000	3000
Orphanned		0.1	3	150	5	2	100	5000	200
Consolidated		1	2	15	10	5	50	20000	2000
Disposed		1	2	10	5	1	100	10000	100

Radioactivity (Ci)		Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources		1200000	10000	1800	2000	5000	100000	80	18
Sales		1000000	10000	1800	1700	5000	100000	20	18
Transported		1000000	10000	1800	1700	5000	100000	10	18
In Use		5000000	10000	1800	5000	5000	100000	5	18
Disused		500000	8000	1800	1000	4000	80000	0.3	18
Orphanned		500000	7000	1800	1000	4000	80000	0.3	18
Consolidated		500000	7000	1800	500	4000	80000	0.2	18
Disposed		250000	6000	1800	500	3500	70000	0.1	18

Approx Impact (1-100)		Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources		10	10	10	10	10	1	10	100
Sales		10	10	10	10	10	1	10	100
Transported		10	10	10	10	10	1	10	100
In Use		10	10	10	10	10	1	10	100
Disused		10	10	10	10	10	1	10	100
Orphanned		10	10	10	10	10	1	10	100
Consolidated		10	10	10	10	10	1	10	100
Disposed		10	10	10	10	10	1	10	100

Inaccessibility (1-100)		Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources		100	100	100	100	100	100	100	100
Sales		100	10	100	5	5	100	1	10
Transported		20	10	100	5	5	10	1	2
In Use		50	2	10	5	5	10	1	5
Disused		25	2	2	5	5	10	1	5
Orphanned		10	5	1	10	10	20	5	10
Consolidated		10	10	10	10	10	10	10	10
Disposed		100	100	100	100	100	100	100	100

Security (1-100)	*Approx*	Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources		100	100	100	100	100	100	100	100
Sales		10	10	10	10	10	10	10	10
Transported		10	10	10	10	10	10	10	10
In Use		100	10	10	10	10	10	1	10
Disused		3	3	3	3	3	3	3	3
Orphanned		1	1	1	1	1	1	1	1
Consolidated		30	30	30	30	30	30	30	30
Disposed		100	100	100	100	100	100	100	100

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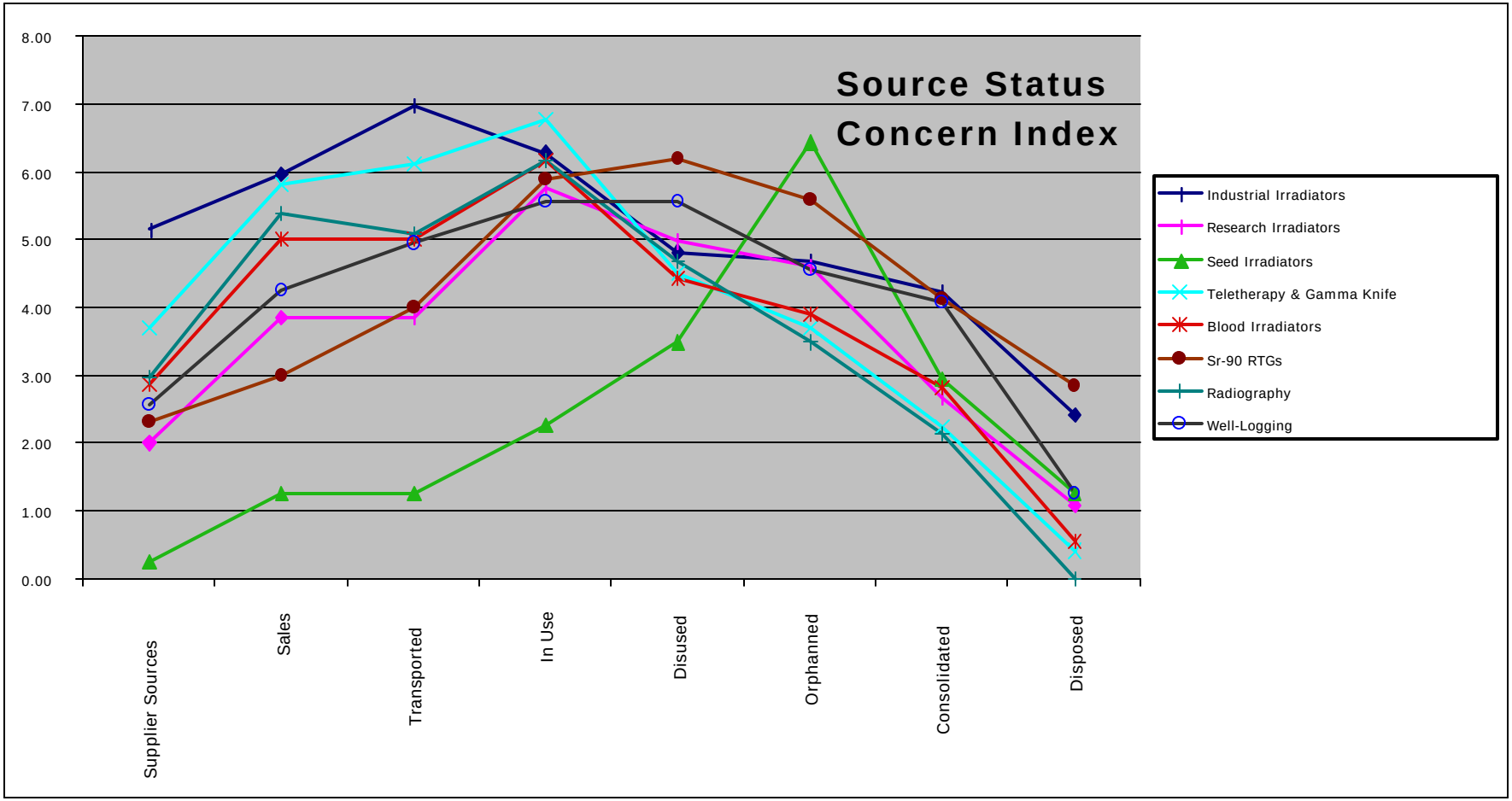
SSCI Results Vary Widely by Source Type and Life-Cycle Stage



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The SSCI Concerns Can Be Ranked as Follows:

1. Transportation of Cobalt-60 Sources
2. Teletherapy Source User Facilities (Hospitals)
3. Disused and Orphaned RTGs
4. Orphaned Seed Irradiators
5. Industrial & Blood Irradiators & Radiography Sources in Use
6. Sales/Re-Sales of Cobalt-60 & Radiography Sources
7. RTGs, Research Irradiators, and Well-Logging Sources in Use
8. Disused Well-Logging Sources
9. Sales/Re-Sales of Radiography Sources and Blood Irradiators
10. Transportation of Radiography, Well-Logging, and Blood Irradiator Sources

Note: This List Covers the Top 2 Orders of Magnitude, with the First 5 in the Highest Order of Magnitude

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Assessing Options to Reduce the Concerns

- The Options can be Grouped According to Type of Action:
  - **Security Actions** Include Facility Upgrades & Source Recovery (Especially Disused and Orphan Sources)
  - **Diplomatic and Regulatory Actions** can Improve Import/Export Laws, Recycling/Disposal Options, Handling Procedures, Transportation Requirements, Security Requirements
  - **Alternate Technology Actions** can Include Replacement of Problem Source Applications, Alternate Isotopes or Chemical Forms, Security Gadgetry
- The Projected Impact of Each Set of Options After Approximately 10 Years was Estimated and New SSCI Scores Generated & Assessed
- An Integrated Program Incorporating All Three Sets of Actions was then Assessed (again, after 10 years)

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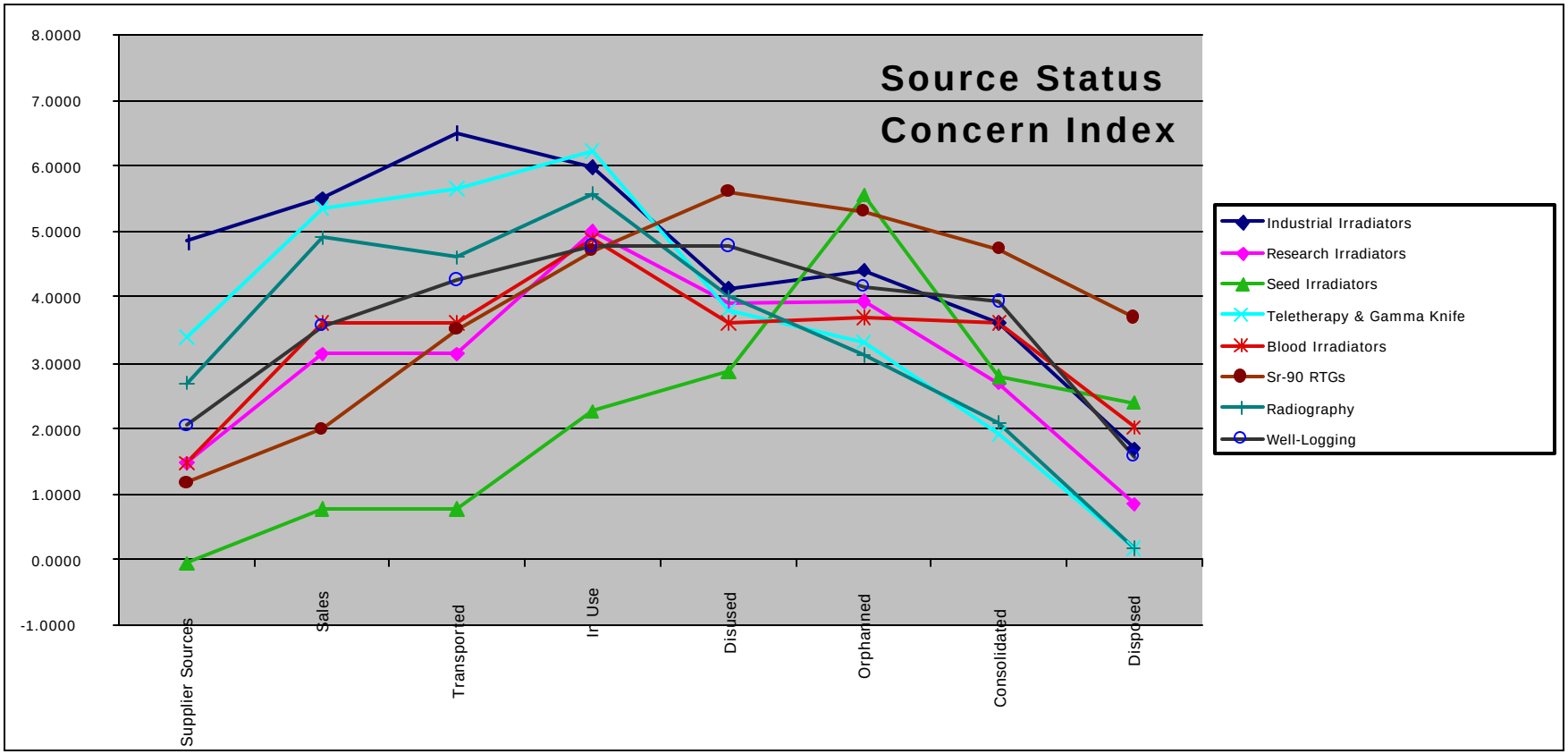
An Integrated Program to Reduce the Concerns Shows Significant Improvements, but Concerns Remain



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Impact of Integrated Program to Reduce Concerns

- All of the Scores Between 5 and 7 were Reduced by at Least 50%, and Some Dropped by 96%
  - 6 of the 8 Highest Scores (6 to 7) Dropped Below 6
  - 8 of the 12 Scores Between 5 and 6 Dropped Below 5
- Two of the Highest Concerns Remained High: Transportation of Cobalt-60 Sources and Teletherapy Sources in Use
- There is some re-ordering of concerns, but mostly the curves shift downward
- The Maximum Effectiveness of an Integrated Global Effort, After 10 Years, May Be An Order of Magnitude Improvement (90%)
  - Some Actual RDD Attacks May be Needed to Achieve the Needed Levels of Cooperation
  - The Cobalt Transportation and Teletherapy Facility Security Issues May Be Limiting

Note that doing nothing results in an increase in the problem over 10 years

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Recommendations

- Repeat the Analyses to Reduce Uncertainties & Improve Fidelity
- Continue Efforts to Detect & Interdict Smuggling of Materials/ Devices and Prepare to Respond to RDD Attacks
- Balance the Options to Reduce Concerns: Quick Fixes Are Helpful but Fundamentally Limited, but Permanent Improvements Can Not Be Implemented Quickly
- Examine the Difficult Problems of Cobalt Transportation and the Wide-Spread Teletherapy Facilities, as these may Limit the Potential Effectiveness of Source Denial Strategies
- Regarding Disused and Orphan Sources: The Biggest Problems are in the FSU. Waste consolidation sites can help reduce the problems with disused and orphan sources.
- Stage the Approaches, As Cooperation May Be Boosted by an RDD Attack

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Major Radioisotope Producers

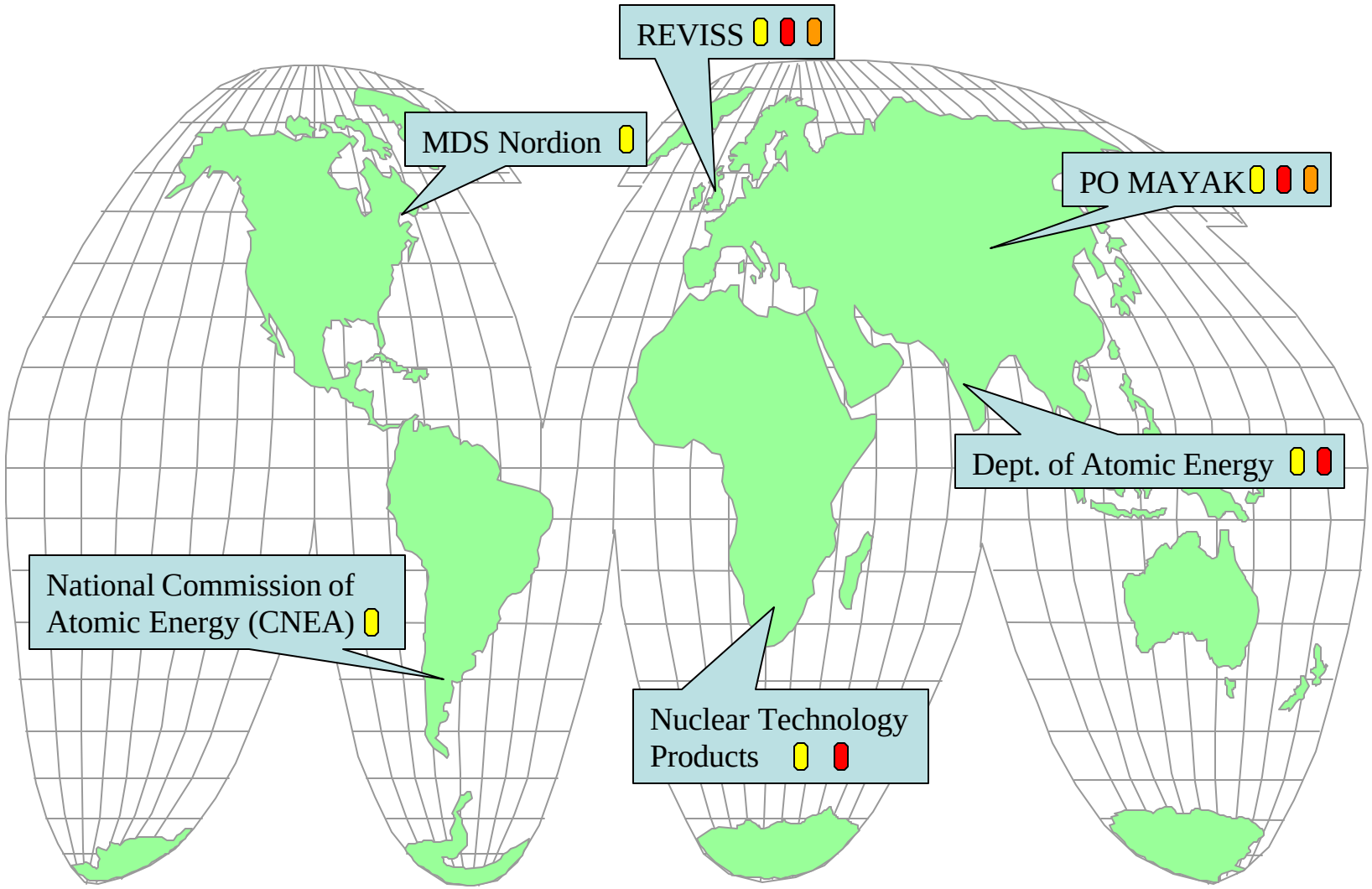

Fig 5.1 Large-Scale Manufacturers of Radioisotopes

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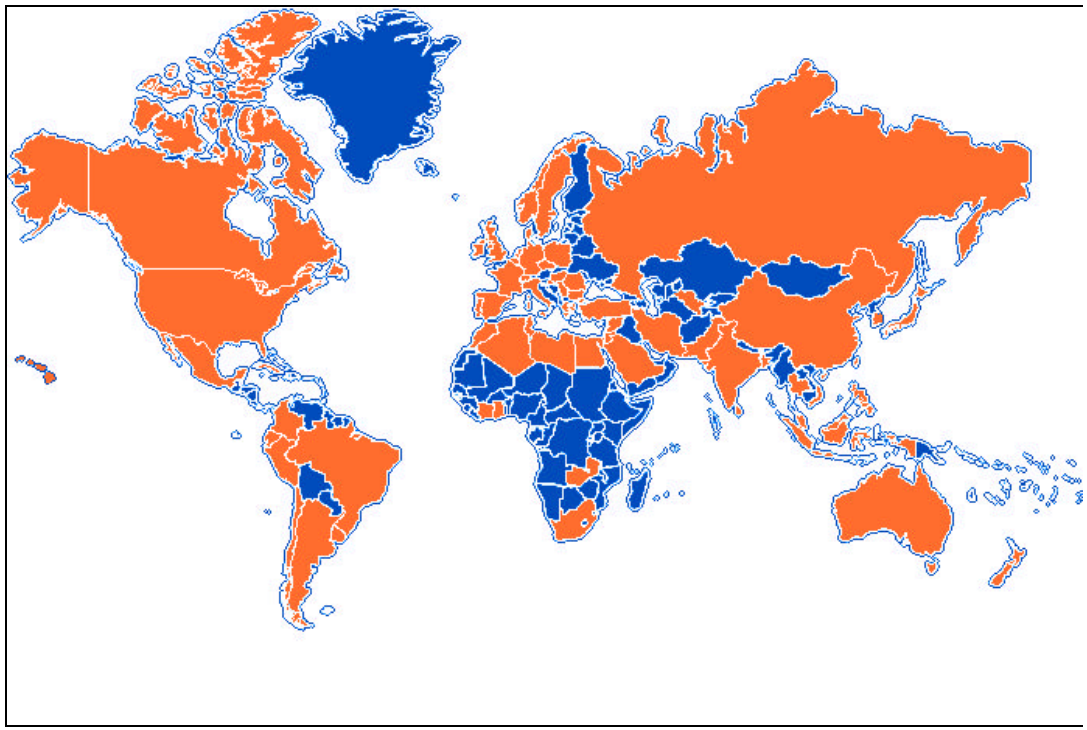
Figure 10. Locations of Large Irradiators/Sterilizers Worldwide



Countries with irradiators/sterilizers are in orange

N-AMERICA: Canada-6, US-34, Mexico-2, Cuba-1. **(43)**
S-AMERICA: Argentina-2, Brazil-6, Chile-2, Colombia-1, Ecuador-1, Peru-1, Uruguay-1. **(14)**
EUROPE: Belgium-3, Bulgaria-1, Croatia-1, Czech Rep-1, Denmark-3, France-5, Germany-4, Greece-1, Hungary-3, Ireland-1, Italy-3, Netherlands-3, Norway-1, Poland-2, Portugal-1, Romania-1, Spain-1, Sweden-1, Switzerland-1, Turkey-3, UK-6. **(47)**
MIDDLE EAST: Iran-1, Israel-1, Jordan-1, Saudi Arabia-1, Syria-1. **(5)**
AFRICA: Algeria-1, Cote d'Ivoire-1, Egypt-1, Ghana-1, Libya-1, Morocco-1, South Africa-3, Tunisia-1, Zambia-1. **(11)**
ASIA: Bangladesh-1, China-4, India-9, Japan-5, Pakistan-2, Russia-1, South Korea-1, Sri Lanka-2, Taiwan-2, Thailand-5, Uzbekistan-1, Vietnam-2. **(35)**
OCEANIA: Australia-5, Indonesia-3, Malaysia-7, New Zealand-1, Philippines-1. **(17)**
TOTAL: 172 facilities, 63 countries

Fig. 5.4 Locations of Large Irradiators/Sterilizers Worldwide

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Per Cent Change	Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources	-50	-70	-51	-50	-96	-92	-50	-70
Sales	-67	-80	-67	-66	-96	-90	-67	-80
Transported	-67	-80	-67	-66	-96	-67	-67	-80
In Use	-50	-83	-1	-72	-95	-94	-75	-83
Disused	-80	-91	-75	-80	-85	-75	-80	-83
Orphanned	-50	-80	-87	-60	-40	-50	-56	-60
Consolidated	-75	5	-33	-50	505	305	-4	-26
Disposed	-80	-40	1245	-40	2928	592	50	98

Table 9.11 Relative change (per cent) in Source Status Concern Index resulting from Integrated Strategy

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Table 3. Alternate Parameters Assuming Integrated Risk Reduction Program

Number of Sources	Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources	120	10	1	2500	20	3	12000	2000
Annual Sales	95	7	1	2000	20	3	12000	1000
Transported	190	7	1	4000	20	10	12000	1000
In Use	190	120	1	6000	500	200	30000	10000
Disused	0.4	2	0.5	20	5	300	20000	1300
Orphanned	0.05	1	20	2	2	50	2200	100
Consolidated	0.5	7	20	10	100	400	38000	3700
Disposed	0.2	2	136	3	50	700	15000	250

Approx Impact (1-100)	Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources	10	6	10	10	6	1	10	60
Sales	10	6	10	10	6	1	10	60
Transported	10	6	10	10	6	1	10	60
In Use	10	6	10	10	6	1	10	60
Disused	10	6	10	10	6	1	10	80
Orphanned	10	6	10	10	6	1	10	80
Consolidated	10	6	10	10	6	1	10	80
Disposed	10	6	10	10	6	1	10	80

Security (1-100) *Approx*	Industrial Irradiators	Research Irradiators	Seed Irradiators	Teletherapy & Gamma Knife	Blood Irradiators	Sr-90 RTGs	Radiography	Well-Logging
Supplier Sources	200	200	200	200	200	200	200	200
Sales	30	30	30	30	30	30	30	30
Transported	30	30	30	30	30	30	30	30
In Use	200	35	10	35	40	40	4	35
Disused	6	6	6	6	6	6	6	6
Orphanned	1	1	1	1	1	1	1	1
Consolidated	60	60	60	60	60	60	60	60
Disposed	100	100	100	100	100	100	100	100

Cs-137 is generally used in Mobile Irradiators

(lower shielding requirements)

Example: Seed Irradiators developed by Soviet Union and orphaned in many FSU States

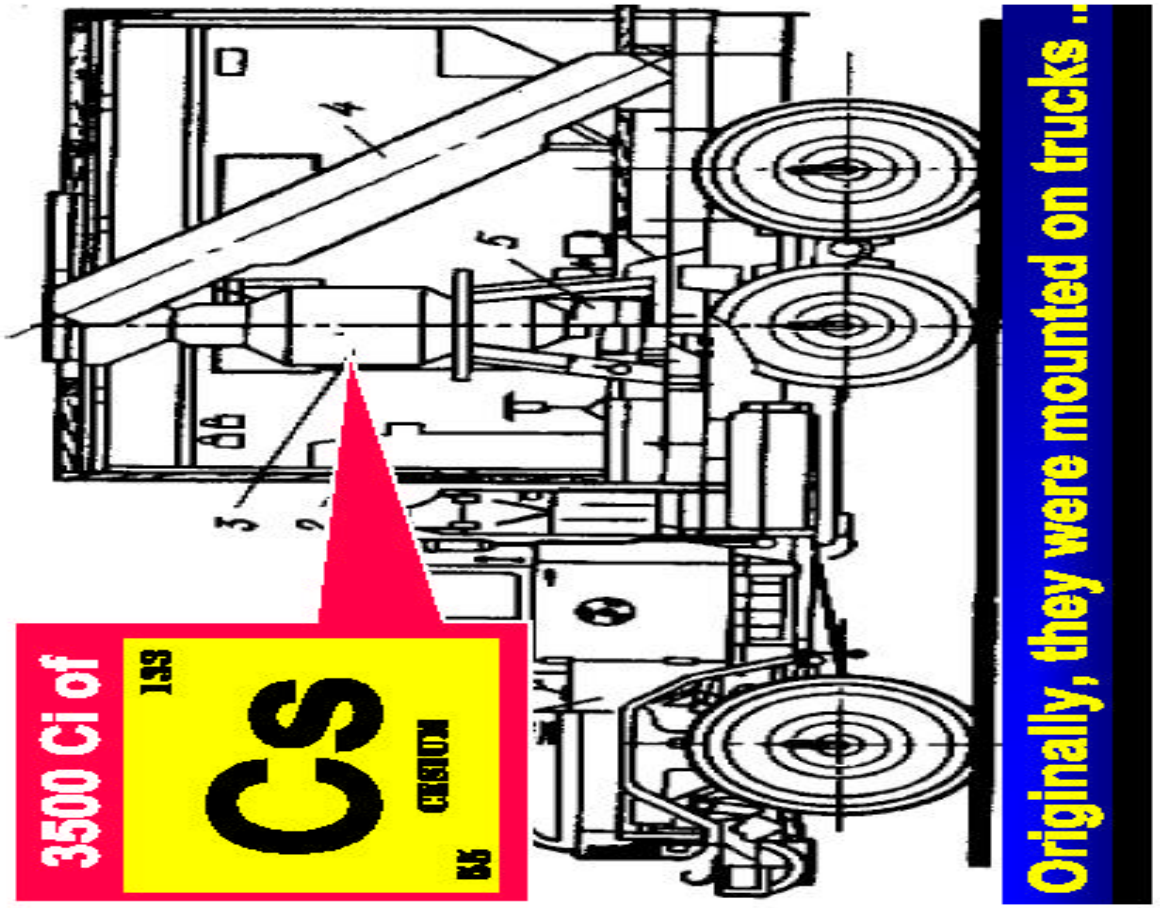

Fig 3.7 Seed Irradiators

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Dose Relative to Cobalt-60 for Radioisotopes Used in Large Applications

Isotope	Half-life	RHM Note 1	CDE Ingest Note 2	CDE Inhale Note 2	RHM/ RHM,Co	Ingest/ Ingest,Co	Inhale/ Inhale,Co
Co-60	5.3 yr	1.37	26900	219000	1.0	1.0	1.0
Cs-137	30.1 yr	0.38	50000	31900	0.3	1.9	0.1
Ir-192	74 d	0.59	5740	28100	0.5	0.2	0.1
Sr-90	29.1 yr	0.00	142000	1300000	0.0	5.3	5.9
Pu-238	88 yr	0.08	3200000	392000000	0.1	119.0	1790.0
Ra-226	1600 yr	0.01	1320000	8580000	0.0	49.1	39.2
Am-241	433 yr	0.31	3640800	444000000	0.2	135.3	2027.4
Cf-252	2.6 yr	0.04	1084100	136900000	0.0	40.3	625.1

Note 1: Rem per hour at 1 meter per curie Note 2: 50 year cumulative dose, per curie

Source: Handbook of Health Physics & Radiological Health by Shleien

Table 4.1 Dose Conversion Factors and Comparison vs. Cobalt-60

A Thresholds Bar can be used to compensate for differing levels of concern regarding radioactivity levels of the different radioisotopes. A simple thresholds bar, based on likely dose impacts is shown below. More sensitive versions could include data on potential dispersion, detection, and decontamination issues

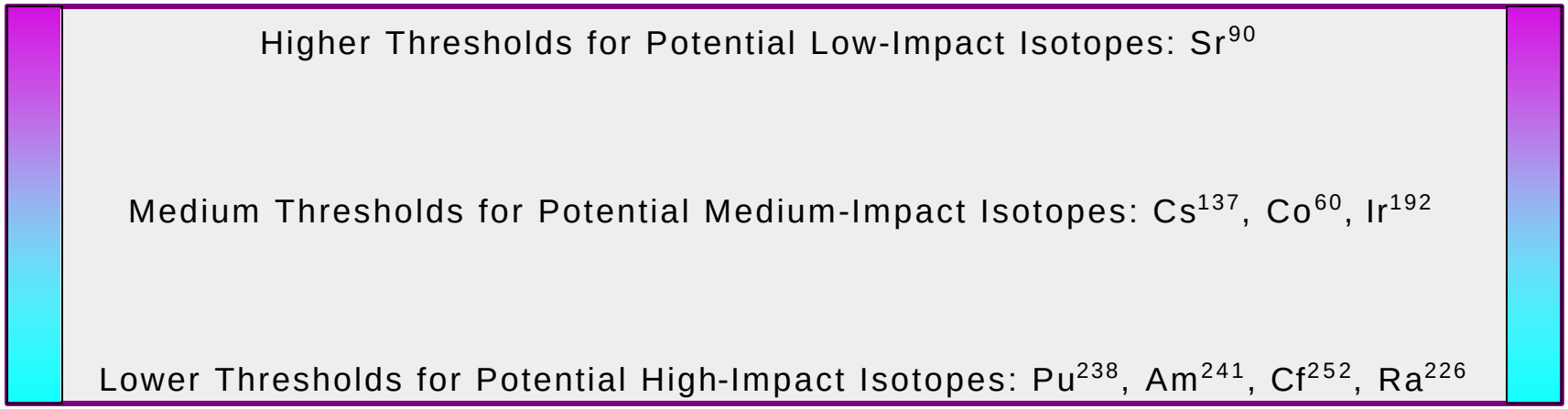

Figure 4.3 Defining a Priority Bar Based only on Potential Doses

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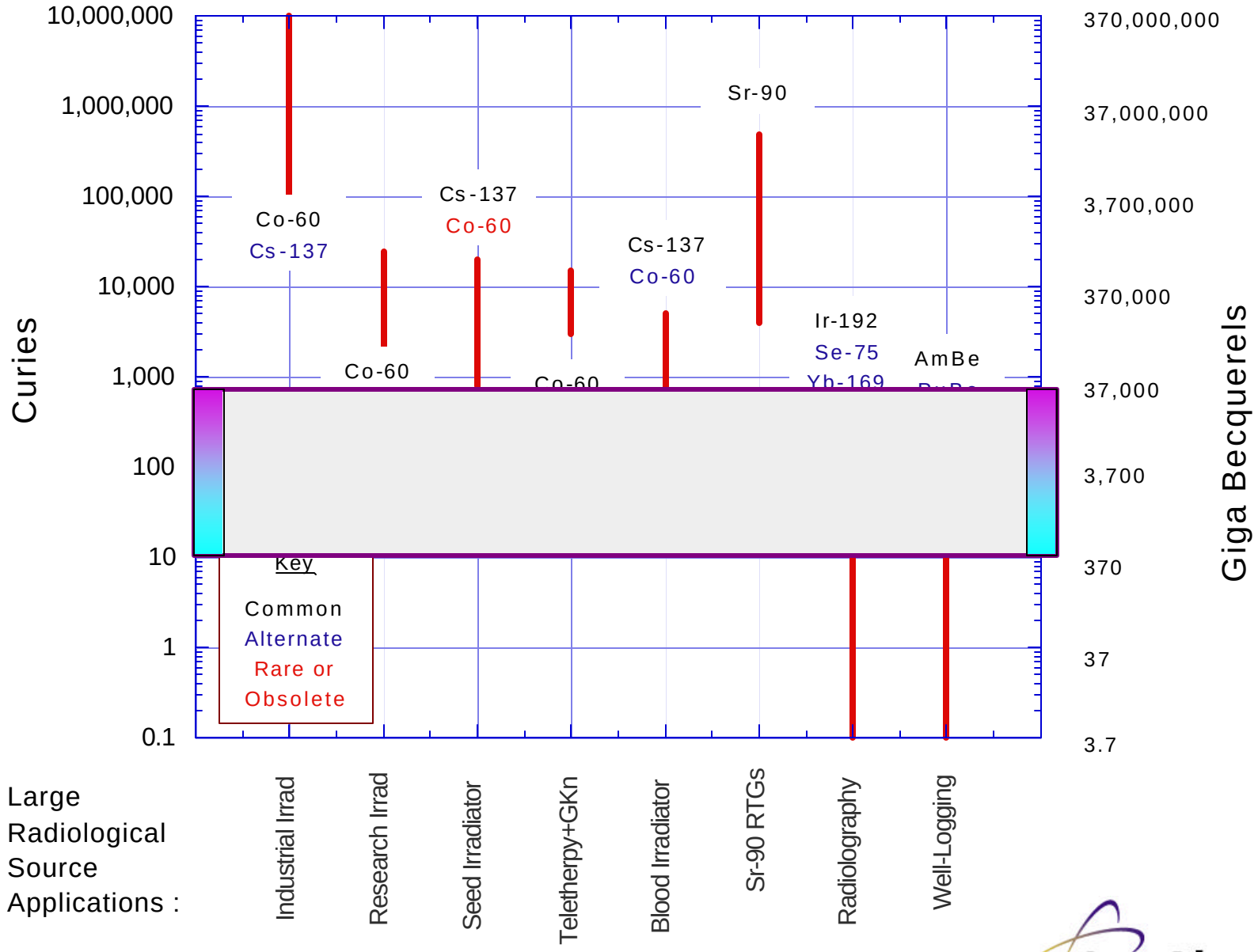

Figure 4.4 Overlay of Priority Bar on Rad Source Chart for Global Program